# Legibility of Digital Type-fonts and Comprehension in Reading

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ABSTRACT

Two experiments were conducted to investigate the effects of font-styles on legibility and on reading proficiency. The font-styles studied include Letter Gothic, Courier, and DECwriter font. Both upper and lower case letters were studied. The results revealed the significant effects of different font-styles, ambiguities between letters, and method of presentation. Directions for future research were suggested.

## 1. Introduction

Advances in computer technology have brought many new methods of conducting research in typesetting and typography. One area which benefits a lot from the use of modern computers is related to type-font design and evluation. With the aid of a computerized optical scanner, characters in different font styles can be read and converted into digital images. Once these images have been binarized [Suen 1986], they can be stored in matrices and reproduced easily by computers and matrix and laser printers. Hence it is not surprising to see that digital fonts have become more and more widely used in the computer environment. While these binary matrices can be stored and used later for printing, they form a new tool to study several subjects in typography such as legibility of font styles, reading speed/comprehension and font style, spacing of words and texts on the page, line lengths and character sizes. These topics have been of great interest to many psychologists and others (see e.g. Burt 1959, Tinker 1963, Hartley et al 1983). Using modern equipment, these topics can be studied much more rigorously and efficiently than before due to the fact that many parameters such as

font styles, character shapes, exposure time, presentation speed, format and spacing, etc. can be controlled precisely by the computer. Our investigation is concentrated on the effects of font-styles on legibility and on reading proficiency.

Three font-styles were studied, viz.: (a) Letter Gothic, (b) Courier, and (c) DECwriter font. These type-fonts were chosen because of their common use and their special properties, i.e. the absence or presence of serifs in Letter Gothic and Courier respectively, and the matrix/letter quality of fonts between the DECfont and the other two. All three type-fonts were first digitized by an optical character reader to produce binary matrices within a frame of 21 dots wide and 42 dots high. This matrix size was chosen so that the characters can be displayed reasonably quickly while at the same time preserving the essential characteristics of the font style. Upper and lower case letters and special symbols of the 3 different digitized type-fonts are shown in Fig. 1. Using these three font-styles, Experiment 1 investigated the legibility of individual letters while Experiment 2 investigated the readability of texts.

## 2. Experiment 1

The legibility of individual characters was ascertained in Experiment 1 by using the visual backward masking paradigm (see Neisser, 1967, for a description of the paradigm). In the backward masking paradigm, a target letter is briefly flashed and then is followed by a masking stimulus after varying periods of time, the inter-stimulus interval or ISI. As Sperling (1963) has demonstrated, as the ISI between the target and mask is increased, the legibility of letters is increased due to the increased amount of time available for the processing of the letters before they are degraded by the mask. With respect to the present experiment, then, letters presented in inherently more legible fonts should lead to superior performance, especially at the shorter ISIs.

### *2.1 Method*

*Subjects.* Three males and three females with normal (20/20) or corrected to normal vision participated in the experiment. The subjects were paid for their participation.

*Apparatus and Stimuli.* Apple II microcomputer was used to generate the stimuli, control the temporal presentation of the letters and mask on a high resolution screen, and acquire and store the responses made by subjects.

*Procedure.* Each subject was tested individually and completed 10 sessions, of approximately two hours, over a period of two weeks. In each session, subjects were presented with each of the three fonts (Letter Gothic, Courier and DECwriter) in combination with each of three ISIs (0, 16.7 and 33.3 ms). The presentation of fonts and ISIs

were blocked within a session while the presentation of the 52 target letters (26 upper case and 26 lower case letters) were randomly presented within each block.

*2.2 Results and Discussion*

The mean percentages of correct responses as a function of font-style and ISI are presented in Table 1. The results shown in Table 1 were subject to a 3 x 3 (Font x ISI) analysis of variance for repeated measures. The analysis revealed a main effect of Font [$F(2,10) = 28.5$, $p<0.001$], a main effect of ISI [$F(2,10) = 70.0$, $p<0.001$] and a significant Font by ISI interaction [$F(4,20) = 4.7$, $p=0.007$]. As can be seen from Table 1, the main effect of Font arises from the overall poorer performance with the DECwriter font.

| Font | ISI(ms) | | |
|---|---|---|---|
| | 0 | 16.7 | 33.3 |
| Letter Gothic | .46(.18) | .87(.07) | .91(.04) |
| Courier | .39(.18) | .89(.05) | .91(.03) |
| DECfont | .28(.13) | .80(.08) | .88(.04) |

Table 1: Mean proportion correct recognition of letters.
Note: standard deviations are presented in brackets.

Consistent with the findings of Sperling (1963), Table 1 also shows that the main effect of ISI arises from the improvement of performance with increases in ISI. However, the most interesting result is the interaction between font-style and ISI. The examination of Table 1 reveals that, at the ISI of zero, performance with the Letter Gothic font was the highest followed by that with the Courier font and that with the DECwriter font was poorest. In contrast, at the ISI of 33.3 ms, performance with all three fonts were very similar. These results, then, suggest that the sans serif font Letter Gothic is the most legible among the three fonts and that the DECfont is the least legible among the three.

Unlike most studies which concentrated on the legibility of either the lower case or upper case letters [see e.g. Mayzner 1975, Gilmore et al 1979, and van der Heijden 1984], the present experiment also studied case differences. In order to assess within font discriminations among the letters, confusion matrices were computed for each of the three fonts for the ISI of 16.7 ms; these results are presented in Table 2. The results presented in Table 2 reveal the following:

FONT # 3 ISI = 16 Case Differentiation

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| B | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| C | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| D | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 11 |
| E | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| F | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 5 |
| G | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| I | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| J | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| K | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| L | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| N | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| O | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 8 |
| S | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| T | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| U | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 10 |
| V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| W | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 10 |
| X | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 9 |
| Y | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Z | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 3 |
| a | 2 | 4 | 3 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| b | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| c | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| d | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| e | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| f | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| g | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| i | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| j | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| k | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| l | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| m | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 21 |
| n | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| o | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| p | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 33 |
| q | 2 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 |
| r | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 8 |
| s | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| t | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| u | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 2 | 0 | 0 | 0 | 24 |
| v | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 1 | 0 | 0 | 0 | 18 |
| w | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 25 |
| x | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 10 | 0 | 0 | 16 |
| y | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 0 | 23 |
| z | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 19 |
| | 22 | 8 | 17 | 11 | 3 | 2 | 9 | 3 | 6 | 9 | 4 | 13 | 3 | 6 | 10 | 9 | 28 | 3 | 17 | 3 | 22 | 24 | 26 | 12 | 7 | 6 | |

**Table 2: Confusion matrix for DECfont, excerpt from entire table of 6 pages.**

Font 3

| | a | b | c | d | e | f | g | h | i | j | k | l | m | n | o | p | q | r | s | t | u | v | w | x | y | z | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| B | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| C | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| D | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 11 |
| E | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| F | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| H | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| J | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| K | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| L | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 |
| M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| N | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| O | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 10 |
| P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| Q | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 |
| R | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| S | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| T | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| U | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 10 |
| V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 6 |
| W | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 0 | 0 | 0 | 10 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 1 | 0 | 9 |
| Y | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Z | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| a | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 28 |
| b | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 9 |
| c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| d | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| e | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| f | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| g | 2 | 1 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 35 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 49 |
| h | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| i | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| j | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| k | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| l | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| m | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 |
| n | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 10 |
| o | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| p | 1 | 0 | 0 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 2 | 10 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 |
| q | 3 | 0 | 2 | 1 | 5 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 46 |
| r | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 8 |
| s | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 9 |
| t | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| u | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 24 |
| v | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 |
| w | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 25 |
| x | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| y | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 23 |
| z | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 19 |
| | 9 | 6 | 10 | 6 | 16 | 1 | 8 | 16 | 2 | 11 | 10 | 7 | 7 | 23 | 17 | 11 | 4 | 18 | 55 | 3 | 12 | 10 | 8 | 5 | 5 | 3 | |

**Table 2: Confusion matrix for DECfont, excerpt from entire table of 6 pages.**

| | Letter Gothic | Courier | DECfont | Sum |
|---|---|---|---|---|
| c-C | 21 | 9 | 10 | 30 |
| C-c | 2 | 21 | 2 | 25 |
| k-K | 3 | 3 | 0 | 6 |
| K-k | 7 | 3 | 10 | 20 |
| o-O | 26 | 0 | 5 | 31 |
| O-o | 2 | 27 | 2 | 31 |
| p-P | 3 | 3 | 7 | 13 |
| P-p | 10 | 11 | 8 | 29 |
| s-S | 20 | 11 | 8 | 39 |
| S-s | 0 | 3 | 2 | 5 |
| u-U | 13 | 1 | 19 | 33 |
| U-u | 1 | 11 | 2 | 14 |
| v-V | 19 | 7 | 15 | 41 |
| V-v | 2 | 20 | 4 | 26 |
| w-W | 25 | 5 | 20 | 50 |
| W-w | 7 | 10 | 5 | 22 |
| x-X | 13 | 11 | 10 | 34 |
| X-x | 6 | 8 | 5 | 19 |
| z-Z | 19 | 8 | 5 | 32 |
| Z-z | 0 | 7 | 2 | 9 |

Table 3: Major erroneous responses due to case differences for ISI=16.7 ms.

(a) Major lower and upper case confusions, e.g. c-C, j-J, k-K, o-O, p-P, s-S, u-U, v-V, w-W, x-X, z-Z as shown in Table 3.

(b) Major letter confusions, e.g. l-I and U-V in Letter Gothic, and a-s, g-s, m-n, p-r, q-Q, and O-D in DECfont as can be seen in Table 2.

Further examination of the results points out the important aspect that while there is a tendency for some lower case letters to be more easily mistaken as their upper case counterparts, including c-C, o-O, s-S, u-U, v-V, w-W, x-X, and z-Z in both Letter Gothic and DECfont; however, this trend does not occur in Courier. To the

contrary, more upper case Courier letters were mistaken as lower case than the other way round including C-c, O-o, P-p, U-u, V-v, and W-w. These trends seem to have more to do with the design of the character shapes in their respective fonts.

Note that case confusions will affect the performance of optical readers in data and text processing [Suen 1986] which must be able to differentiate upper and lower case characters correctly. This effect is more accute in military applications and cryptography where lower case and upper case letter confusions could be catastrophic.

In the Letter Gothic font, the small v shape at the bottom part of U produced 8 errors as V, and the short horizontal bars on top and bottom of I resulted in 7 l-I confusions.

The large number of letter confusions between letters in the DECfont suggests its deficiency in resolution as a 5 x 7 matrix font. A considerable number of confusions were caused by the absence of descenders in the lower case letters.

Based on the above findings, one can correct the deficiencies by modifying the shapes of the characters and re-design the type-fonts to make them more legible, e.g. by making the characters with similar shapes more distinct and emphasizing their different features.

## 3. Experiment 2

The results of Experiment 1, then, indicate that differences in font-style can influence the legibility of individual letters. However, whether the results obtained in Experiment 1 can be generalized to reading is not clear. Investigators such as Rumelhart (1977) suggest that reading is accomplished through a set of interactive processes. In particular they suggest that a skilled reader utilizes his or her knowledge of the language ( e.g., the orthographic, syntactic and semantic contsraints in a language) to facilitate the recognition of individual words and, thereby, increase reading proficiency. From this point of view, the more readers use their knowledge of the language the less the reliance on the purely visual characteristics of the texts being read. This implies that differences in font styles may not influence reading proficiency.

Accordingly, Experiment 2 assessed the effects of different font-styles on the readability of texts wherein subjects were required to read texts presented using the rapid sequential visual presentation (RSVP) procedure for comprehension. (See Potter et al, 1980, for a description of the RSVP procedure.) In the RSVP procedure, the words that comprise the text being read are presented singly in rapid sequential order. Using the RSVP procedure, the rationale for

Experiment 2 is that the more legible a font, the higher the comprehension of texts presented in that font should be for a given rate of presentation.

### *3.1 Method*

***Subjects.*** Nineteen females and 17 males with normal or corrected to normal vision who were paid for their participation served as subjects. Subjects' reading proficiency were assessed using a reading test by Educational Testing Service (Don Mills, Ontario). The mean reading rate of subjects to achieve at least 70% comprehension was 320 words per minute.

***Apparatus and Stimuli.*** The apparatus used in Experiment 2 and the manner in which letters were displayed were similar to that used in Experiment 1. However, in Experiment 2, whole words rather than single letters were presented at a rate of 600 words per minute. All words, irrespective of length, were presented for the same duration and centered on the monitor screen.

The texts presented were 32 paragraphs taken from different articles published in READER'S DIGEST. Five paragraphs served as practice texts while the remaining 27 texts served as experimental texts. All paragraphs were approximately 160 words in length.

***Procedure.*** The 27 experimental texts were divided into three groups of nine texts. Each group of texts was paired with each of the three fonts (e.g., Letter Gothic, Courier and DECwriter font) to produce nine combinations of text group and font-style. These nine combinations were used to produce nine different orders of presentation such that a) each order presented each font and each text group once and b) over orders, each font-text group combination appeared equally often in each position of the order of presentation (e.g., first, second or third). Each subject, assigned randomly to each order or presentation, read each text, albeit, in different font-styles.

### *3.2 Results and Discussion*

The results of interest are the total number of questions correctly answered over the nine texts presented in each of the three fonts, results which are presented in Table 4. The results in Table 4 were analyzed using a one-way analysis of variance for repeated measures with Font being the only factor. As suggested in Table 4, the analysis revealed a significant effect of Font [$F(2,70)=11.3$, $p<0.001$]. As is apparent from Table 4, the highly significant result of the analysis arises from the poorer performance with the DECwriter font. As in the case of Experiment 1, the DECwriter font appears to be the least legible font.

| Font | Mean | SD |
|---|---|---|
| Letter Gothic | 31.1 | 4.34 |
| Courier | 31.0 | 4.44 |
| DECfont | 27.9 | 4.17 |

Table 4: Mean number of multiple-choice questions answered correctly over nine texts.

On the one hand, the results of Experiment 2 appear to be consistent with those obtained in Experiment 1. That is, whether in terms of single letter identification or of the readability of texts, DECwriter font produces the lowest level of performance. Again, such results may not only be due to the dot-matrix format of the font but also may be due to the lack of ascender and desender elements within the font. On the other hand, the results of Experiment 1 and Experiment 2 are not entirely consistent. In Experiment 1, the Letter Gothic font was found to be more legible than the Courier font. However, in Experiment 2, very little, if any, differences was observed in the reading performance of texts presented in the two fonts. Thus, the reading skills and strategies brought to the reading situation can apparently attenuate the effects of the purely visual characteristics of the texts being read.

## 4. Conclusion

The results obtained in Experiments 1 and 2 suggest that when materials are presented in an unfamiliar font (i.e., the DECwriter font) both the legibility of individual characters and the readability of texts are diminished. Given these results and with the advent of dot-matrix printers, questions arise about the legibility and readability of texts printed with such printers. One avenue of future research is, then, an examination of the legibility and readability of materials printed with various dot-matrix printers, especially those with ascenders and descenders. Given the findings from the confusion matrices, another fruitful direction for research is to examine whether the systematic redesign of individual characters would yield a font in which individual letters would be more legible and texts written in such a font, more readable.

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## 5. *REFERENCES*

[1] Burt, C. (1959). *A Psychological Study of Typography*, Cambridge: Cambridge University Press.

[2] Gilmore, G. C., Hersh, H., Caramazza, A. & Griffin, J. (1979). "Multidimensional letter similarity derived from recognition errors," *Perception & Psychophysics*, vol. 25(5), 425-431.

[3] Hartley J. & Rooum, D. (1983). "Sir Cyril Burt and typography: a re-evaluation," *British Journal of Psychology*, vol. 74, 203-212.

[4] Mayzner, M. S. (1975). "Studies of visual information processing in man," in *Information Processing and Cognition*, ed. R. L. Solso, pp. 31-54, Hillsdale, N. J.: Lawrence Erlbaum Associates, Publishers.

[5] Neisser, U. (1967). *Cognitive Psychology*, Englewood Cliffs, N. J., Prentice-Hall.

[6] Potter, M. C., Kroll, J. F. & Harris, C., (1980). "Comprehension and memory in rapid sequential reading," in *Attention & Performance VIII*, ed. R. Nickerson, Hillsdale, N. J.: Erlbaum.

[7] Poulton, E. C. (1965). "Letter differentiation and rate of comprehension in reading," *J. Applied Psychology*, vol. 49(5), 358-362.

[8] Rumelhart, D. E. (1977). "Toward an interactive model of reading," in *Attention & Performance VI*, ed. S. Dornic, Hillsdale, N. J.: Erlbaum.

[9] Sperling, G. (1963). "A model for visual memory tasks", *Human Factors*, vol. 5, 19-31.

[10] Suen, C. Y. (1986). "Character recognition by computer and applications," in *Handbook of Pattern Recognition and Image Processing*, eds. T. Y. Young & K. S. Fu, Orlando: Academic Press.

[11] Suen, C. Y. & Shiau, C. (1980). "An iterative technique of selecting an optimal 5X7 matrix character set for display in computer output systems," *Proc. Soc. Infor. Display*, vol. 21(1), 9-15.

[12] van der Heijden, A. H. C., Malhas, M. S. M. & van den Roovaart, B. P. (1984). "An empirical interletter confusion matrix for continuous-line capitals," *Perception & Psychophysics*, vol. 35(1), 85-88.

[13] Tinker, M. A. (1963). *Legibility of Print*, Ames, Iowa: Iowa State University Press.